About Drought

Maximising the impact of UK research on drought & water scarcity

Streams and Rivers

Report Card 2020

This publication covers the effects of drought and water scarcity on streams and rivers, the ecosystem response, future impact scenarios and possible mitigation actions.
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It is designed to be used by all, including the general public
It is one of a series of report cards summarising current and future aspects of water scarcity in the UK's main ecosystems.

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UKRI Natural Environment Research Council

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Drought in UK streams and rivers

Droughts and water scarcity are projected to become more severe and prolonged in the UK with an increase in demand for water (e.g. agriculture, industry and potable water) as the population grows, and the impact of climate change.

Humans contribute to the impacts of water scarcity in the river environment by abstracting water from aquifers and rivers, by building dams and weirs, and by, principally, managing rivers for flood conveyance. Human society derives key goods and services from streams and rivers, which could be threatened by water scarcity, affecting both regional and national economies.

Droughts and water scarcity vary in duration, frequency, intensity and spatial extent. Some droughts are regional, others national; they can occur in winter or summer; they can be short-lived or span multiple years; they can be manifested as reduced river flows or as completely dried out river beds; each drought event is unique and, therefore, its impacts are context specific.

It is important to distinguish between droughts in freshwater ecosystems under both natural and altered conditions. Humans affect droughts and their impacts by abstracting water, adding nutrients to water, changing the climate and modifying channels. Under natural conditions, droughts are part of the continuously varying hydrological conditions in streams and rivers, as are floods. Droughts can lead to the death of organisms, disconnection, shrinkage of habitat, etc. but this can be natural. Under unnatural conditions, droughts can become more severe, i.e. increased frequency and intensity or exacerbating other stressors on fresh waters. Here, we describe the potential impacts of severe droughts on UK streams and rivers.

The sediment load, water quality and water temperature of streams and rivers is affected during low flows as dilution is reduced. This has direct consequences for livestock and human health, and on wildlife, but it also drives up the cost of maintaining fisheries and water treatment. Some unique UK river habitats, such as chalk streams, are dependent upon predictable flow regimes and may become permanently damaged by sustained water scarcity. As each drought event is unique so is each habitat; for example, the difference in adapted river ecology of salmonid- versus cyprinid-dominated populations, makes the impact of drought variable and site-specific.

There are many things that we can do to reduce the impacts of drought in river environments and help build resilience, including better adaptive river channel and catchment management, adapting water resource planning, as well as more efficient water use.

Photo: Side Channel, Howden Reservoir, 2018. Copyright K. Muchan

Drought is a natural phenomenon. Water scarcity is human-related, because we need the right amount of water of the right quality at the right time and in the right place

Severity, impact & recovery from drought

This table shows the severity of damage to streams and rivers during drought and illustrates at which stage different impacts can be expected. Freshwater systems can recover quickly from some types of drought, to the point that one cannot tell there was any impact. Typically, the response period to a drought can be considered under natural conditions as: short (during the drought); medium (immediately after the drought), and; long (cycles of drought and wet periods). Below we highlight likely long-term and notable impacts, especially where they are linked to other stressors or long-term processes. Although the impacts of drought on systems altered by humans are complex, we attempt to outline the likely future impact scenarios in the tables that follow.

	Severity of damage to the riverine system		
Likelihood*	Mild	Moderate	Severe
Low			River planform and shape change rapidly in response to changes in riparian vegetation structure
Medium		Serious disruption to fish migrations	Eutrophication is exacerbated and localised fish kills occur
High	Short-term changes to riverine animal communities occur intra-annually	Plant and animal community structure changes gradually over time in response to more frequent small droughts	River planform and shape change gradually over time in response to changes in riparian vegetation structure

* Likelihood is a coarse indicator of a drought instigating damage to the system. It is a combination of the change in duration, timing and volume of the events, and their frequency. Each drought has unique characteristics leading to site-specific responses. As an example, the summer of 2018 water scarcity / drought event created conditions of moderate and severe impacts, and the chances of similar droughts occurring again is classified as 'medium'.

Eutrophication is the over-supply of nutrients causing excessive growth of nuisance algae and aquatic plants

Stages of drought

As flow decreases, margins recede and the river is disconnected from its riparian zone (Left: Winterbourne Stream). The flow will eventually stop, leaving isolated pools of water (Centre: River Ems). Finally the bed dries, disconnecting the river from this hyporheic zone (Right: River Lavant).

Loss of lateral connectivity
Margins recede

Loss of longitudinal connectivity
Flow stops

Loss of vertical connectivity
Bed dries

Riparian zone is where land and water meet. It is important for the health of streams/rivers, contributing to the balance of nutrients, oxygen and sediment, providing both habitat and food for animals. Hyporheic zone is the region of sediment and porous space beneath and alongside a stream/river bed where there is mixing of shallow groundwater and surface water.

Habitats affected by drought

Habitat complexity confers resilience to drought for benthic freshwater invertebrates. Pool areas (2), woody debris (3), boulders (4) and aquatic plants (5) can all function as refugia for invertebrates during drought conditions. Riparian shading (6) will limit the increase in water temperature during summer drought conditions, protecting both invertebrates and fish.

Photo: Copyright F.K Edwards

Zones

1) Diverse flow environment
2) Pool areas
3) Woody debris
4) Boulders
5) Plant margins
6) Riparian shading
7) Meanders

Freshwater invertebrates are animals without backbones that spend at least part of their life cycle in fresh waters, e. g. flatworms, insect larvae, leeches, shrimps, snails and worms

Mitigating Actions – Physical

Physical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Reduction in water flow restricts connectivity and alters instream hydraulic habitats (depth, force and speed of water) (Meier et al., 2003; Poff et al., 2002). These physical changes underpin the impacts on biological and chemical processes that, in turn, alter both channel stability and river biodiversity. Drought and water scarcity may exacerbate other stressor impacts on rivers, the magnitude of which are dependent on the reduction in volume, duration, timing and rate of change in water flow.	Decrease in lateral connectivity leads to long-term changes in the riparian zone, potentially, altering channel mobility. Longitudinal and lateral connectivity alterations reduces species distribution and diversity, as will changes to the instream hydraulic habitat.	Permanent change in connectivity, hydrology and instream hydraulics.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).
Reduction in water flow, allows air temperatures and solar radiation to increase water temperatures, potentially leading to heat stress in freshwater animals, as well as accelerating decomposition rates and lowering dissolved oxygen concentrations, thereby, causing anoxic conditions especially, during the night (Suren et al., 2003). For smaller, groundwater-fed streams, temperatures may also decrease due to a lower addition of warmer surface water (Dewson et al., 2007).	Heat stress and lower oxygen content in streams and rivers will result in a degradation in their ecological status and cause a change in the biological community.	Permanent degradation of ecological status and change to the instream biota.	**M3** Planting riparian vegetation will create areas of shadow, limiting radiation and temperature rises.

Chemical effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Decrease in water flow reduces dilution, potentially concentrating solutes and increasing conductivity and pHs (van Vliet & Zwolsman, 2008; Wilbers et al., 2009; Zielinski et al., 2009). An increase of nutrient concentrations may be counterbalanced by lower additions from the catchment and, thereby, relatively higher additions of nutrient-poor groundwater (Caruso, 2002; Dahm et al., 2003; Golladay & Battle, 2002). The ratio of inorganic to organic nutrients may be lowered (Dahm et al., 2003).	Increase in nutrient concentrations is likely to lead to eutrophication, changes to biology and reduced recreational value.	Permanent degradation of ecological status and change to the instream biota.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M4** Releasing flushing flows from reservoirs may scour algae from channel and help reduce eutrophication.
Lower water flow decreases suspended particles and turbidity in the water (Bond, 2004; McKenzie-Smith et al., 2006). As a consequence, particulate organic matter is likely to accumulate in river channel beds (Pinna & Basset, 2004), although this may be partly compensated for by a reduction in additional sediment derived from the catchment (McKenzie-Smith et al., 2006).	Accumulation of fine sediments could lower water flow and reduce availability of certain habitats for all biotic levels, leading to changes in biodiversity.	Permanent degradation of ecological status and change to the instream biota.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).
Dehydrated, exposed sediments may cause changes to the chemistry, microbiology and mineralogy of the river/stream bed. The anoxic layer in the sediments may deepen, leading to a reduction in microbial biomass and denitrification, an increase in phosphate retention and, potentially, re-oxidation of sulphur to sulphates (Baldwin & Mitchell, 2000; Lamontagne et al., 2006).	Changes to oxygen conditions in the sediment, may decrease microbial activity and change fundamental functions.	Permanent dried river bed.	**M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015). **M5** Reducing weed management (e.g. weed cutting) will retain water and can make the river more resilient to drought.

Mitigating Actions – Biological 1

Biological effects of drought & mitigating actions

<table>
<tr><th>Effects</th><th>Response</th><th>Impact Scenarios</th><th>Mitigation</th></tr>
<tr><td>Riparian vegetation: Plants growing on river margins bind the banks together and interact with flow to determine the shape of UK rivers (Gurnell et al., 2016). Severe droughts may lead to plants on the river margins dying, resulting in the increased erosion of banks and significant changes in river form. This kind of impact has not yet been observed in the UK but if we had an unprecedented drought, then the riparian vegetation could die back (O'Hare et al., 2016), although it is unclear how likely this is.</td><td>Riparian vegetation dies and bank collapse occurs with significant channel re-alignment.</td><td>The most detrimental scenario would be a prolonged summer drought starting late spring followed by winter flooding
Well-established modelling procedures can ascertain the potential impact of future drought scenarios (Auble et al., 1994; Strom et al., 2012). The most damaging droughts are likely to be during the growing season and with long-term shifts in drought patterns.</td><td>M2 Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).

M6 Compensation flows are required. There is significant modelling capability to identify vulnerable systems and quantify the size and timing of eflows that sustain the vegetation, e.g. UKCEH's Riparian Modelling Suite.</td></tr>
<tr><td>The loss of lateral connectivity can significantly alter the floodplain and riparian vegetation structure. This habitat loss can be substantial and is dependent on the duration, periodicity and seasonality of droughts.</td><td>Loss of riparian habitats results in a reduction of vegetation and available habitat for amphibians, birds, mammals and specialist invertebrates.</td><td>Permanent loss of riparian habitats and increase in soil dryness.</td><td rowspan="2">M1 Improved water management during droughts (e.g. SEPA, 2019).

M2 Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).

M5 Reducing weed management (e.g. weed cutting) will retain water and can make the river more resilient to drought.

M6 Compensation flows are required. There is significant modelling capability to identify vulnerable systems and quantify the size and timing of eflows that sustain the vegetation, e.g. UKCEH's Riparian Modelling Suite.</td></tr>
<tr><td>During drought progression there is a shift from aquatic to terrestrial vegetation, and the strength and span of the drought controls the severity of this process and can influence instream vegetation too (Westwood et al., 2006; Wright & Berrie, 1987). The alteration changes the channel outline, notably, conjoint with increased deposition (Franklin et al., 2008).</td><td>Changes to the river channel.</td><td>Permanent change in hydrology and vegetation community.</td></tr>
</table>

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation	
Eutrophication: In rivers the most significant short-term effect of droughts is to exacerbate eutrophication. Sluggish water flows may not wash away algae growing on the river bed and so may accumulate to nuisance levels (Kinzie et al., 2006; O'Hare et al., 2018; Wade et al., 2002). The lack of nutrient dilution and higher temperatures may compound the problem. Excessive demand for oxygen by the algae and aquatic plants at night or when they begin to rot, can lead to fish kills, as it did across the UK in summer 2018 (*Figure 1*).	Deoxygenation, excessive aquatic plant growth and fish kills. Shift in algal dominance to species capable of withstanding eutrophication and higher water temperatures.	The role of aquatic plants in mitigating drought is likely to become more significant.	**M3** Planting riparian vegetation will create areas of shadow, limiting radiation and temperature rises. **M4** Releasing flushing flows from reservoirs will scour algae from channel and help reduce eutrophication.	 *Figure 1:* Dead salmonid fish float in the shallow, slow water of the River Stinchar in 2018, after prolonged water scarcity. Excessive algal growth is visible. Photo: copyright G. Hislop.
Benthic algae and biofilms: Shifts in community structure can occur (Caramujo et al., 2008; Suren et al., 2003). Prolonged drought and rapid changes dry out biofilms (Ledger & Hildrew, 2001; Ledger et al., 2008). Mucilage and resting stages (cysts) can help the assemblages withstand this (Stanley et al., 2004) and deeper areas can serve as a refuge (Robson & Matthews, 2004).	Desiccation of the river bed can lead to changes in community composition.	Permanent dryness of river bed.	**M7** Reducing weed management (e.g. weed cutting) will help retain water. This can provide habitat refugia for biota (algae, aquatic plants, fish, and invertebrates).	
Aquatic plants can act as a natural mitigation against drought by blocking flow and increasing water depth (O'Hare et al., 2010) (*Figure 2*). The time of travel of water down a channel can increase threefold and elevate the water table in surrounding fields. As vegetation only blocks flow during summer, it effectively targets the season when fish and invertebrates are most vulnerable.	During droughts, vegetated channels are more resilient and can retain water for longer.	The role of aquatic plants in mitigating drought is likely to become more significant.	**M8** Adaptive weed management plans are needed to maximise the benefit of aquatic plants. Weed cutting should be stopped during summer droughts.	*Figure 2:* Aquatic plants growing in this stream block water flow, increasing flow depth and slowing the travel of water downstream. This sustains, otherwise, absent habitats and mitigates the impact of droughts. Photo: copyright UK Centre for Ecology & Hydrology.

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Aquatic plants (cont.): The impacts of drought can fundamentally change a river plant community by eradicating certain species, thereby, allowing more opportunistic species to establish (Lake, 2011). As aquatic plants die, the organic material deposited on the river bed and bank can serve as a refuge for other biota, keeping the moisture despite increasing drought (Lake, 2011). The seedbank can allow aquatic plants to recovery from drought (Brock et al., 2003; Romanello et al., 2008; Touchette et al., 2007).	Loss of more sensitive species within river plant community resulting in a loss of biodiversity.	Loss of seedbank and, thereby, potential reduction in distribution or extinction of species.	**M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015). **M9** Allowing room for the river to shape naturally will increase the resilience to drought.
Invertebrates: Droughts need to be prolonged and widespread to have long-term impacts on invertebrates. Within a season, however, marked differences in the abundance distribution and species composition of invertebrates can be observed, with knock- on effects for other groups such as fish. This response is dependent on the system size and there are a number of direct and indirect effects at play, these are described below.	Initially, causing a lower abundance of invertebrates, however, recovery can be fast.	Ultimately, prolonged and severe droughts might cause major changes to species distribution and composition.	**M7** Reducing weed management (e.g. weed cutting) will help retain water. This can provide habitat refugia for biota (algae, aquatic plants fish and invertebrates).
In terms of distribution, at the onset of drought, the decrease in flow and water level can accumulate invertebrates in the remaining water, making the relative numbers rise (Dewson et al., 2003; McIntosh et al., 2002). This concentration increases competition and predation that will, ultimately, cause a decrease in invertebrates (Wood et al., 2000). During droughts, instream hydraulics change and species adapted to lower flows and finer sediment habitats can have an advantage over species with a preference for greater flows and coarser sediment (Everard, 1996). The change in velocity can also lead to a rapid decline in filter feeders and other rheophilic (i.e. flow preferring) species (Dewson et al., 2007). Species with brief life cycles may also have an advantage due to the lower risk of drought effects during that time (Bonada et al., 2006; Bonada et al., 2007; Dewson et al., 2007). Less motile species living in shallower waters, such as freshwater mussels, risk desiccation (Gagnon et al., 2004; Golladay et al., 2004).	Decrease in habitat availability will increase competition and predation. Declining environmental conditions will favour some species.	The impact on invertebrate species diversity is small if habitat heterogeneity is maintained during a drought (Boulton & Lake, 2008; Lake, 2011; Ruegg & Robinson, 2004; Smith et al., 2003).	**M7** Reducing weed management (e.g. weed cutting) will help retain water. This can provide habitat refugia for biota (algae, aquatic plants, fish and invertebrates). **M10** Maintaining habitat heterogeneity will help ensure resilience of invertebrate diversity (see image, page 5).

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Invertebrates (cont.): Invertebrate abundance and species composition may also be directly affected by the impact of drought on their food resources, such as algae (Smakhtin, 2001), and indirectly affected by decreased oxygen levels due to increased primary production. This eutrophication favours species suited to poorer water quality and impacted stream environments (Boulton, 2003; Lake, 2011).	Decrease in food availability may increase competition, and degraded habitats will favour certain invertebrate species.	Long-term anoxic conditions may cause a shift in invertebrate species composition.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M4** Releasing flushing flows from reservoirs will scour algae from river channel and help reduce eutrophication. **M10** Maintaining habitat heterogeneity will help ensure resilience of invertebrate diversity (see image, page 5).
Invertebrates in smaller streams are, inherently, more vulnerable compared with larger, deeper rivers where drying out is slower and, potentially, less severe (Bonada et al., 2006; Bonada et al., 2007; Lake, 2011; Wood & Armitage, 2004; Wood et al., 2005). Bigger species have higher evaporation rates and need larger areas of wetted habitat and will, therefore, be at greater risk during droughts (Dewson et al., 2007; Ledger et al., 2011).	Habitat and species specific conditions affect the severity of impact.	Larger invertebrates and communities in smaller streams are likely to be more severely affected by droughts.	
Benthic invertebrates are widely used in biomonitoring and, in general, assemblage quality will decrease in drought years for the reasons outlined above. For management purposes, it is important to be able to distinguish this effect from the multiple other stressors impacting on rivers.	Biomonitoring may become more difficult during droughts.	Development of new tools (e.g. eDNA techniques) for monitoring river ecosystem health may be needed to supplement existing methods to detect drought impacts from other stressors.	**M4** Releasing flushing flows from reservoirs will scour algae from river channel and help reduce eutrophication. **M7** Reducing weed management will retain water. This can provide habitat refugia for biota (algae, aquatic plants, fish and invertebrates). **M10** Maintaining habitat heterogeneity will help ensure resilience of invertebrate diversity (see image, page 5).

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Fish: As with the other biological groups, there are a number of processes effected by droughts with direct and indirect impacts on fish. During the water scarcity of 2018, there were localised fish kills in UK rivers resulting from de-oxygenation events. This is one of the most visible and contentious impacts of droughts and is directly linked to changing instream hydraulic conditions and is exacerbated by eutrophication. Other potential key effects of droughts on fish include, loss of habitat quality and reduced food availability and migration.	Fish kills.	Loss of recruitment, leading to reduction in fish stock.	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015). **M3** Planting riparian vegetation will create areas of shadow, limiting radiation and help keep water temperatures low. **M4** Releasing flushing flows from reservoirs will scour algae from river channel and help reduce eutrophication. **M7** Reducing weed management (e.g. weed cutting) will help retain water. This can provide habitat refugia for biota (algae, aquatic plants, fish and invertebrates).
Migration of ana- and catadromous fish could be hindered during supra-seasonal droughts, especially in systems with other artificial obstacles (de Leaniz, 2008; Fukushima, 2001; Jonsson & Jonsson, 2002; Vadas, 2000). This can have significant economic consequences for sports fisheries where the number of fish making it up through the catchment is reduced.	Decline or loss of ana- and catadromous fish. Quality of sports fishery declines.	Change in abundance, distribution and diversity of ana- and catdromous fish.	
The decrease of invertebrates during droughts may have an impact on fish, as this will deplete their food resource (Hakala & Hartman, 2004).	Increase in competition for food for fish.	Loss of recruitment, leading to reduction in the fish stock.	**M10** Maintaining habitat heterogeneity will help ensure resilience of invertebrate diversity (see image page 5).

Anadromous fish, for example, salmon and sturgeon, are born in fresh water, but spend most of their life in the sea, returning to fresh water to spawn
Catadromous fish (including most eels) live in fresh water but spawn in salt water

Biological effects of drought & mitigating actions

Effects	Response	Impact Scenarios	Mitigation
Fish (cont.), especially those requiring high levels of oxygen (e.g. salmon and trout), are likely to concentrate in deep pools with well-oxygenated water. There may also be a shift in the behaviour and the type of habitat used by fish with decreasing flow, e.g. dominating behaviour and pecking orders vanish (Elliott, 2006). At first, fish may reorganise, specifically, to search for pools in shaded areas (Dekar & Magoulick, 2007; Elliott, 2000; Matthews & Marsh-Matthews, 2003; Pires et al., 2010). During a drought, the regulation of salmonid population size may become more density-independent compared with density-dependent regulation when there is no drought (Elliott, 2006; Nicola et al., 2009).	Decrease in fish abundance and distribution.	With flow continuously decreasing, fish can be stranded in remaining pools, which can increase the risk of harm from terrestrial predators and the spread of infections and parasites (Magalhães et al., 2002).	**M1** Improved water management during droughts (e.g. SEPA, 2019). **M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).
Water quality can be reduced locally (Antolos et al., 2005; Dekar & Magoulick, 2007; Labbe & Fausch, 2000; Maceda-Veiga et al., 2009; Magalhães et al., 2007). These conditions will affect fish species composition and their distribution even after the drought is over (Matthews & Marsh-Matthews, 2003; Lake, 2011).	Advantage for more robust species – more sensitive species may decline.	Change in species composition and potential loss of certain sensitive species.	**M3** Planting riparian vegetation will create areas of shadow, limiting radiation and temperature rises. **M4** Releasing flushing flows from reservoirs will scour algae from river channel and help reduce eutrophication.
Decreasing flow might cause fish eggs to die due to deposition of fine sediments and fish fry may also become more exposed to predation during droughts (Hakala & Hartman, 2004; Magalhães et al., 2007).	Siltation adversely effects recruitment.	Long-term change in fish abundance and composition.	**M2** Constructing channels designed to withstand reductions in flow and connectivity (Everard, 2015).

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